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RECOMMENDED PRACTICES FOR COMMERCIAL HUMAN SPACE FLIGHT

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In 2013, the U.S. Federal Aviation Administration (FAA) released "Established Practices for Human Space Flight Occupant Safety," a draft guidance document for the rapidly developing commercial human space flight industry. The initial draft document was intended to facilitate a discussion with stakeholders, with the hope of gaining a consensus among government, industry, and academia on practices related to human space flight occupant safety. In September 2014, the FAA released an updated version entitled "Recommended Practices for Human Space Flight Occupant Safety." The document provides a framework for industry to use in developing industry consensus standards. It can also serve as a starting point, should there be a need for the government to issue regulations at some point in the future. One of the main challenges in preparing the practices was to accommodate the diverse system designs and potential future plans of U.S. industry. Some U.S. companies are focused on carrying people and experiments on short-duration suborbital missions that launch and land at the same location. Other companies are planning launches to low Earth orbit, with visits to government or commercial space stations. Some of the systems will land like an airplane, while others will use a vertical landing, either on land, or in the ocean. Companies participating in NASA's Commercial Crew Program would like to be able to develop a single vehicle that can meet NASA requirements for carrying astronauts, while still accommodating the needs of commercial customers and having the capability to be operated at reasonable prices. The FAA practices are based on the data gathered and lessons learned from more than 100 years of aviation and over 50 years of human space flight. Commercial aviation has provided significant insights on the need for regulatory balance, both in terms of business viability, and with respect to passenger safety. Government space programs have helped identify crucial design features and operational capabilities that have been shown to be very important during previous human space flights. In preparing the FAA practices, the FAA did not want to stifle technology innovation, or to see occupants exposed to avoidable risks. This paper will provide an overview of the FAA's Recommended Practices for Human Space Flight Occupant Safety, including a discussion of how they were prepared, and how they could be used to enhance occupant safety while accommodating a wide range of design approaches and technical challenges.

I. INTRODUCTION

For over 50 years, human space flight has been an activity carried out by governments. In the United States, commercial companies are currently in the process of developing capabilities to achieve both suborbital and orbital flights. Creating the right set of conditions to enable new vehicles to meet the requirements of both government and commercial customers is a challenge for policymakers and safety regulators.

With the passage of the 2004 Commercial Space Launch Amendments Act (CSLAA) by the U.S. Congress, the U.S. Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) was given clear authority to regulate commercial human space flight.[1] However, in order for the new industry to grow and develop, Congress restricted the issuance of new regulations that were designed to protect the safety of the people onboard.

Congress stated that: "The regulatory standards governing human space flight must evolve as the industry matures so that regulations neither stifle technology development nor expose crew or space flight participants to avoidable risks as the public comes to expect greater safety for crew and space flight participants from the industry."[2]

An eight-year period was established during which the FAA could not propose regulations for occupant (crew and space flight participant) safety. The FAA's ability to ensure the safety of the general public (on the ground) was not affected. Space flight participants and crew are required to be informed in writing by the launch or reentry operator about hazards and risks associated with their space flight. Each occupant is required to sign an informed consent document. The occupants will be informed that the vehicles they have chosen to fly on have not been certified as safe by the government. Flying on commercial space transportation vehicles could be dangerous and would be done at personal risk, unlike how risk is handled for a passenger on a U.S. commercial airliner.

The FAA issued regulations to carry out the CSLAA in 2006.[3] By early 2012, with no commercial human flights since the Ansari X Prize was won in 2004, but with progress in suborbital development and a new NASA Commercial Crew Program underway, the Congress passed an extension of the "moratorium" on new regulations until October 2015. In addition, Congress instructed the FAA to enter into a dialog with industry to discuss potential human space flight regulations and practices.

This paper will provide an overview of the FAA's *Recommended Practices for Human Space Flight Occupant Safety* document, which was released in 2014. The paper will also discuss how the practices were prepared, how the FAA accommodated a wide range of commercial vehicles and missions, and how the document may be of interest to the international community.

II. GATHERING STAKEHOLDER INPUT

From August 2012 to April 2013, the FAA held a series of eight public teleconferences with the Systems Working Group of the Commercial Space Transportation Advisory Committee (COMSTAC). COMSTAC is made up of representatives from the aerospace industry, and provides advice to the FAA.

The teleconferences covered eight different topics: levels of safety, FAA oversight, types of requirements, definitions, aborts, fault tolerance, medical issues, and communications. Input from industry assisted the FAA in narrowing the areas of concern and focus. The process also helped the FAA understand how industry was interpreting the practices, which led to significant improvements in the written text.

Concurrently, the FAA had been working with NASA to prepare for the Commercial Crew Program, which will enable U.S. and other astronauts to fly to and from the International Space Station (ISS) on commercially operated vehicles. Operational crew transport missions will be licensed by the FAA. Planning for this effort brought together two agencies with different objectives and different experience. The differences are also useful in illustrating the FAA approach to its recommended safety practices.

NASA is a research and development agency with over fifty years of experience in human space flight and with existing safety requirements for its crews. It has a clear mission to ferry U.S. and international crews to and from the ISS. In the past, NASA has been willing and able to fund and dictate the design of high quality, multi-purpose human space vehicles to meet a large number of detailed safety requirements. NASA requirements in human space flight cover both mission assurance and verification, and incorporate a number of government and industry standards.

In contrast, FAA/AST is a regulator focused on public safety. In general, FAA/AST does not regulate vehicle design or perform flight certification (unlike the way the FAA handles aviation). AST rules are largely performance-based. Mission assurance is undertaken by the licensee, not the FAA. FAA rules apply to all commercial space transportation licensed and permitted operations, rather than to specific vehicles. A key question for the FAA and NASA to address in the Commercial Crew Program was: Can industry build and operate a single vehicle that can meet NASA's ISS crew transportation needs, while still being affordable for future commercial (non-NASA) customers, when operating under FAA launch and reentry licenses?

After a series of discussions, the FAA and NASA signed a Memorandum of Understanding (MOU) in June 2012 to coordinate standards for the commercial transport of government and non-government astronauts to and from low-Earth orbit and the International Space Station (ISS). The two agencies agreed to provide a stable framework for the U.S. space industry, avoid conflicting requirements and multiple sets of standards, and advance both public and crew safety. Commercial providers will be required to obtain a license from the FAA for public safety. Under the MOU, crew safety and mission assurance will be NASA responsibilities. This approach allows both agencies to incorporate experience and lessons learned as progress is made in the program.[4]

In addition to receiving inputs for the safety practices document from industry and NASA, the FAA conferred with the FAA Civil Aerospace Medical Institute (CAMI) and the FAA's Center of Excellence for Commercial Space Transportation (COE), which involves professors and students at a number of universities across the country. The FAA also reviewed existing government and private sector requirements and standards, including those from the European Space Agency and the International Association for the Advancement of Space Safety, as well as other FAA space and aviation requirements.

Although numerous other references were identified, the FAA's primary guide in developing the recommended practices was the collection of requirements and other guidance that NASA had prepared for the Commercial Crew Program.[5] The NASA requirements provided comprehensive and detailed coverage of occupant safety considerations. The FAA reviewed these requirements to determine whether they could be translated into top-level, performance-based practices that would be both applicable and appropriate for commercial human space flight activities.

The FAA Office of Commercial Space Transportation released draft *Established Practices for Human Space Flight Occupant Safety* to COMSTAC in July 2013. A revised draft that incorporated rationales was released in September 2013, and additional comments were requested from industry, NASA, and academia. In September 2014, the FAA released a baseline version of document, retitled as *Recommended Practices for Human Space Flight Occupant Safety.*[6] The following sections discuss the 2014 document.

III. PURPOSE AND SCOPE OF THE RECOMMENDED PRACTICES

The purpose of the FAA's *Recommended Practices for Human Space Flight Occupant Safety* document is to provide a compilation of practices that the FAA believes are important for commercial human space flight occupant safety. The document is intended to enable a dialog and perhaps a consensus of government, industry, and academia on practices that would support the continuous improvement of the safety of launch and reentry vehicles designed to carry people. In addition, the document can help to identify areas that would benefit from the development of industry consensus standards. The document may also serve as the starting point for future FAA rulemaking, should there be a need for such an effort at some point in the future. The current document, however, is not a regulation, and it has no regulatory effect.

The scope of the document includes both suborbital and orbital launch and reentry vehicles. The document only addresses occupant safety. It does not cover either public safety or mission assurance.

Although the FAA has existing regulations (14 Code of Federal Regulations), the approach taken by the FAA was to start with a "clean sheet" by assuming no other regulations act to protect occupants from harm.

The recommended practices cover occupants from the time they are exposed to vehicle hazards prior to flight until after landing. For orbital missions, the baseline assumption is that any orbital vehicle will stay in Earth orbit for a maximum of two weeks and can return to Earth in under 24 hours if necessary.

Not specifically included in the scope of the document are extravehicular activity (EVA), orbital rendezvous and docking, flights beyond Earth orbit, or flights longer than two weeks. The document does not address how a designer or operator would verify that it meets each safety measure. Future versions of the document could include these topics.

While some medical considerations are described,[7] the document does not attempt to include criteria that would limit who should fly in space due to their medical condition -- space flight participants should be free to make decisions about their own individual risk.

Although methods can be used to reduce human exposure to ionizing radiation, no ionizing radiation exposure limits are included because the recommended practices aim to avoid serious injuries or fatalities, not long-term health effects.

IV. LAYOUT OF THE RECOMMENDED PRACTICES

Recommended Practices for Human Space Flight Occupant Safety is divided into three categories of practices: Design, Manufacturing, and Operations. Figure 1 illustrates the accompanying subcategories.

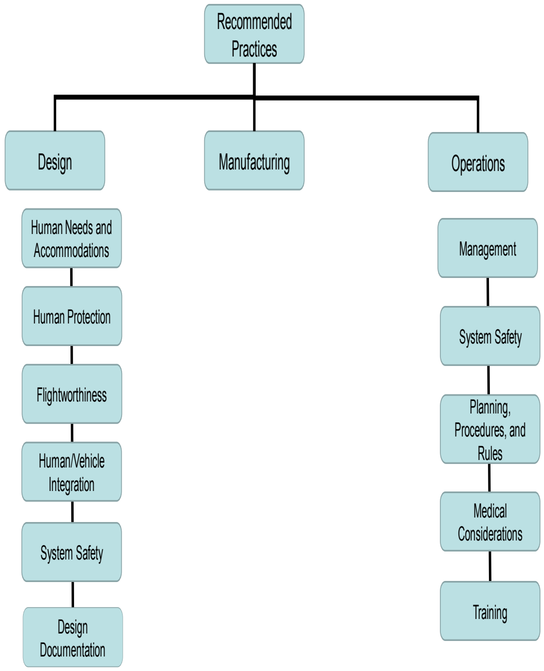

Figure 1: Recommended Practices Framework

Altogether, there are 90 recommended practices, with 54 covering Design, 3 related to Manufacturing, and 33 on Operations. In general, the practices are broadly written and include supporting paragraphs on rationale. Future industry-developed standards could build on some of the recommendations by providing more depth, while future versions of the recommendations could include additional material on manufacturing practices.

In keeping with existing FAA commercial space transportation regulations, the FAA recommended practices are primarily performance-based. Safety objectives are stated, while specific design or operational solutions are left to the designer or operator.

Furthermore, the FAA has refrained from listing hard numerical limits where possible, because there is often no consensus on specific values. Such limits may unnecessarily constrain design flexibility, and they may not stand the test of time as technology advances. Recommendations are provided for three process-based practices: system safety, software safety, and payload safety. These three areas address hazards that are unique to a particular design or operation.

A crucial characteristic to understanding approaches used in the document is the difference between a “system” and a “vehicle.” A system, as defined in the document, is an integrated composite of personnel, products, subsystems, elements, and processes that when combined together will safely carry occupants on a planned space flight. A vehicle is defined as a portion of a space flight system that is intended to fly to, operate in, or return from space. This includes any launch vehicle, carrier aircraft, equipment, and supplies, but excludes payloads. As an example of the difference, recommendations for Failure Tolerance to Catastrophic Events are applied to the overall system, since a vehicle and its associated ground systems, procedures, and training can often work together to provide failure tolerance.

V. DIVERSITY OF DESIGNS

One of the main challenges for the FAA Human Space Flight Team[8] in preparing the recommended practices was determining how to deal with the wide range of proposed commercial vehicle designs and the significant variety of potential flight profiles and mission plans.

Some companies are focused on suborbital vehicles that are intended to carry people and experiments on short-duration flights with launch and landing at the same location. Some of these vehicles can carry multiple people in a relatively large cabin that would permit them to fully experience the joys of weightlessness, while others have smaller cabins with room for only one space flight participant. Some piloted suborbital vehicles will have the capability to deploy upper stages carrying satellites. Point-to-point suborbital travel is also under consideration.

Other companies are planning launches to low Earth orbit, with visits to the ISS or commercial space stations. Some orbital-capable vehicles will land like an airplane with wheels on a runway, while others will use a vertical landing with parachutes, either on land, or in the ocean. Companies participating in NASA’s Commercial Crew Program would like to be able to develop a single vehicle that can meet NASA requirements for carrying astronauts, while still accommodating the needs of commercial customers (including companies and foreign governments), and having the capability to be operated at reasonable prices.

Based on all of these factors, it may be that different levels of risk are appropriate for different situations. Moreover, insisting on a single level of risk may inadvertently limit innovation. Therefore, the FAA did not try to establish a single level of risk for all commercial human space flight systems. Collectively, however, the application of the recommended safety practices will ensure that occupant safety is considered throughout the life cycle of a space flight system and that occupants are not exposed to avoidable risks.

VI. LEVEL OF RISK AND CARE

The document identifies three levels of care for occupants (space flight participants and flight crew). First, occupants should not experience an environment that would cause a serious injury or fatality when they are exposed to hazards (from prior to flight until after landing when they are no longer exposed to hazards). The first level is considered to be a low bar, i.e., below the level of comfort that most space flight participants would want to experience.

Second, the level of care for flight crew when performing safety critical operations is increased to the level necessary to perform those operations. It should be noted that the FAA assumes that each member of the flight crew is safety-critical. In addition, the FAA assumes that space flight participants may be called upon to perform limited safety-critical tasks, such as emergency egress and restraining themselves in their seats.

The third level of care applies to emergencies. In emergencies, occupants should have a reasonable chance of survival. Most of the FAA practices regarding emergencies are covered in the Design section, while two practices on operations management and survival equipment training are located in the Operations section. Practices related to emergencies are listed in Table 1.

Recommended Practice
Emergency Survival Equipment and Supplies
Emergency Response to Contaminated Atmosphere
Emergency Response to Loss of Cabin Pressure Integrity
Emergency Response – Abort and Escape
Emergency Occupant Location Post-Landing
Emergency Communication with Rescue Personnel
Emergency Control Markings
Emergency Equipment Access
Emergency Lighting
Emergency Vehicle Egress
Occupant Survivability Analysis
Emergency Operations Management
Emergency Survival Equipment Training

Table 1. Practices Addressing Emergencies

VII. NOTABLE RECOMMENDATIONS

The following section contains examples of notable recommendations in the FAA practices document.[9]

Loss of Cabin Pressure

Section 1.2.10 of the Recommended Practices document covers "Emergency Response to Loss of Cabin Pressure Integrity." Because there are many different vehicle designs with correspondingly different missions, the FAA approach to the loss cabin pressure is not to require pressure suits for all occupants, but to give guidance on options for industry with supporting rationale. The recommendation states the following:

"In the event cabin pressure integrity is lost, the vehicle should be designed to prevent incapacitation of flight crew and serious injury of occupants by providing:

a. Enough pressurant gases to maintain cabin pressure; or

b. A pressure suit or other equivalent system that makes available environmental control and life support capability for the occupants.

Rationale: Space flight takes place in an extreme environment such that without protection from the environment's extremely low pressures and wide ranging temperatures, life cannot be sustained. Full and partial pressure suits have historically been used to protect the human from these elements when cabin pressure failures occur. With improvements in technology, reliability, and redundancy in environmental control and life support systems, the use of emergency systems such as pressure suits may not always be required. In some cases, such as short suborbital flights, enough gas or cryogenic fluid can be stored to sustain minimal cabin pressure in the event of a leak for the period of time that it would take to return the vehicle back to atmospheric conditions that can sustain life."

Abort and Escape

Section 1.2.11 of the document covers "Emergency Response – Abort and Escape." It notes that:
"The system should provide the capability to abort, escape, or both, during pre-flight and ascent.

Rationale: The capability to respond to an imminent catastrophic hazard (e.g., loss of thrust, loss of attitude control, vehicle explosion, etc.) can provide occupants with a reasonable chance of survival. Escape includes safely returning the occupants to Earth in a portion of the space flight system normally used for reentry and landing, or by the removal of the occupants from the portion of the space flight system normally used for reentry and landing. While a successful abort or escape may not be possible for every imaginable event, history has shown that having the capability to abort, escape, or do both, significantly enhances occupant safety."

Failure Tolerance

Section 1.3.1 of the document addresses "Flightworthiness - Failure Tolerance to Catastrophic Events." It recommends that:

a. "The system should control hazards that can lead to catastrophic events with no less than single failure tolerance.

b. When failure tolerance adds complexity that results in a decrease in overall system safety or when failure tolerance is not practical (e.g., it adds significant mass or volume), an equivalent level of safety should be achieved through design for minimum risk.

Rationale: Failure tolerance can mitigate hazards leading to catastrophic events and improve the overall system safety. In cases where the risk remains high after applying single failure tolerance, additional redundancy may be appropriate. Additionally, the overall system reliability is a significant element used in the determination of the level of redundancy. Redundancy alone without sufficient reliability does not improve the overall system safety.

Note that failure tolerance applies not only to "must work" functions, such as preventing over-pressurization burst of the crew compartment, but also to "must not work" functions, such as ensuring crew compartment pressure relief valves do not open inadvertently or leak excessively.

Where failure tolerance is not the appropriate approach to control hazards, specific measures should be employed to achieve an equivalent level of safety. This is commonly known as "design for minimum risk." Measures that may achieve an equivalent level of safety include demonstrated reliability, design margin, and other techniques that compensate for the absence of failure tolerance."

Emergency Location and Communications

Two FAA safety recommendations discuss emergency transmitters and communications. Historically, for NASA's Mercury, Gemini, and Apollo missions, the Department of Defense would stage assets in advance and be ready to pick up astronauts and capsules in the ocean or be relatively close by for off-target reentries. For the Space Shuttle, NASA identified specific transoceanic abort landing sites (such as in Morocco or Spain) with pre-positioned recovery teams and also identified and established agreements for emergency landing sites in global locations with suitable runways. For a pure commercial mission without NASA as the main customer, a commercial company may not have those government-mission advantages in the event of an emergency return -- especially to an unplanned location -- and may be limited by funding resources. This makes locators and communications all the more important.

Section 1.3.13 of the Recommended Practice document, "Emergency Occupant Location Post-Landing," states that: "The vehicle should:

a. Have a portable transmitter to provide occupant location to rescue personnel post-landing; and

b. Be equipped with visual aids to assist rescue personnel.

Rationale: In an unforeseen or emergency situation, the vehicle may not land at its preplanned location. Experience has shown that providing rescue personnel with information as to the vehicle's location increases their probability of being found, thereby increasing their chance of survival. A portable transmitter, such as an Emergency Locator Transmitter, that is independent of vehicle systems (e.g., power, antenna) allows the locator to remain with the occupants if they must leave the vehicle area. Visual aids such as flashing lights, sea dye, smoke, or high contrast portions of the vehicle assist rescue personnel in locating the vehicle."

The next recommendation, in section 1.3.14, "Emergency Communication with Rescue Personnel," states that:

"Post-landing, the vehicle should be capable of communicating with rescue personnel on an International Air Distress (IAD) frequency.

Rationale: In an unforeseen or emergency situation, communicating with rescue personnel improves the occupants' probability of being rescued, thereby increasing their chance of survival. Communicating on an International Air Distress (IAD) frequency (121.5, 243, or 406 MHz for voice communication) follows search and rescue standards and allows for worldwide coverage. Human space flight history provides numerous examples of vehicles failing to land at their preplanned landing location, and of those searching to find them"

VIII. INTERNATIONAL INTEREST IN FAA PRACTICES

Although the document was primarily intended for U.S. developers and operators, the FAA recognizes that there may be international interest in the FAA's recommended practices. Under U.S. law, any U.S. citizen (person) or an entity organized under the laws of the United States or any State must obtain a license from the FAA to launch a launch vehicle either inside the United States or outside the United States. The law also applies to a U.S. citizen or entity organized under U.S. law to reenter a reentry vehicle inside or outside the United States.[10] The FAA does not license launches or reentries "the Government carries out for the Government,"[11] such as launches conducted by and for NASA, or by and for the Department of Defense.

As a result, a review of the practices document may provide insights concerning compatibility with future U.S. regulations. For example, other countries seeking to attract U.S. vehicles to launch from or reenter into their territory may find this document useful as a top-level description of regulatory philosophy. The document could also serve as a model for developing domestic legislation and regulations for launches and reentries or spaceport (launch or reentry site) operations. Furthermore, international astronauts (or other space flight participants or crew) who fly on U.S. commercially operated vehicles may find it beneficial to familiarize themselves with the contents of the document.

In the future, with the development of point-to-point transportation through space, interoperability between countries may be a crucial consideration. As seen in civil aviation, merging incompatible regimes can be a costly endeavor. International entities (including both operators and component suppliers) may view the document as a helpful resource for ensuring occupant safety.

IX. FUTURE UPDATES

The *Recommended Practices for Human Space Flight Occupant Safety* document will evolve as the commercial space transportation industry evolves. The baseline version of the document contains 90 different recommendations and is intended to be a foundation to build upon. Going forward, the FAA plans to continually modify the document based on industry feedback and experience. Future versions may also include material on EVAs, docking and rendezvous practices, more manufacturing practices, integration of occupant and public safety, verification of safety measures, long duration space flight missions, and missions beyond low Earth orbit.

REFERENCES

[1] Commercial Space Launch Amendments Act of 2004, Public Law 108-492, 118 Stat. 3978.

[2] Ibid.

[3] Human Space Flight Requirements for Crew and Space Flight Participants, 71 FR 75616 (2006-12-15) http://www.gpo.gov/fdsys/pkg/FR-2006-12-15/pdf/FR-2006-12-15.pdf

[4] "NASA, FAA Advance National Goals in Commercial Human Space Transportation with Landmark Agreement," June 18, 2012, NASA and FAA news release, 12-190. http://www.nasa.gov/home/hqnews/2012/jun/HQ_12-190_NASA-FAA_MOU.html

[5] Specifically, NASA's CCT-PLN-1120 (Crew Transportation Technical Management Processes), CCT-REQ-1130 (International Space Station Crew Transportation Certification and Services Requirements Document), and CCT-SSD-1150 (Commercial Crew Transportation Evaluation of Technical Standards).

[6] "Recommended Practices for Human Space Flight Occupant Safety," August 2014. Available at http://www.faa.gov/about/office_org/headquarters_offices/ast/news_announcements/

[7] The health of the crew is critical to protecting public safety. Recommendations in the document that cover medical and related training include: Flight Crew Medical Fitness Aerospace Physiology Training for Flight, Space Flight Participant Medical Consultation, Health Stabilization and Medical Planning, Medical Training, and Emergency Survival Equipment Training.

[8] The FAA team consisted of: Randy Repcheck, Dave Gerlach, Tom Martin, Mike Machula, Rene Rey, Henry Lampazzi, Jeff Sugar and Misty Snopkowski.

[9] Recommended Practices for Human Space Flight Occupant Safety," August 2014. Available at http://www.faa.gov/about/office_org/headquarters_offices/ast/news_announcements/

[10] Commercial Space Launch Act, 51 U.S.C. Chapter 509. Available at: http://www.faa.gov/about/office_org/headquarters_offices/ast/regulations   Under Title 51, § 50902, Definitions: "In this chapter— (1) ‘‘citizen of the United States’’ means— (A) an individual who is a citizen of the United States; (B) an entity organized or existing under the laws of the United States or a State; or (C) an entity organized or existing under the laws of a foreign country if the controlling interest (as defined by the Secretary of Transportation) is held by an individual or entity described in subclause (A) or (B) of this clause."

[11] Ibid. § 50919, g, 1.